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ACCEPTANCE TESTING OF THE SCORPIUS SWEEP MAGNET

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Summary

A beam-dump magnet for Scorpius [1] has been defined by LANL and designed and built by Radiabeam Technologies. Initial verification of the Radiabeam design used a magnetic field model provided by Radiabeam [2] and analyzed by LANL tools during September 2021 [3]. Simulations indicated that the design was sufficient to meet deflection requirements to protect sensitive equipment in the case of a failed target. In January 2022, the magnet was fabricated and Radiabeam conducted measurements of the magnetic field as a function of position. The measurements deviate somewhat from the simulation. In particular, the peak magnetic field is 10-15% smaller in magnitude than expected from simulation. This note compares the magnetic field measurements to simulation and to measurements of the existing DARHT magnet, which was designed for the same purpose. We show a comparison of the measured beam deflection performance between Scorpius and DARHT and show updated results of LANL's electron beam tracking code using the Scorpius measurements. Using field measurements we find that the DARHT magnet will deflect a 19.6 MeV electron beam by 46.6° and the Scorpius magnet will deflect by 44.6°. These results show that the as-built Scorpius magnet has met design requirements for beam deflection.

Results and Discussion

In [3], we showed results of LANL simulation code running electron deflection calculations with a two-dimensional Radiabeam field model. In the simulation the field was found to be sufficient, with some margin, to completely deflect the full-energy electron beam into the polycrystalline diamond beam-dump in the case of a failed target using typical DARHT beam divergence values.

Radiabeam conducted Hall probe measurements of the as-built magnet in early January 2022 [4]. The dominant component of the magnetic field (denoted B_x) was measured for various positions nearby the magnet. Figure 1 shows measured and simulated field values at different vertical positions along the centerline of the magnet. The peak magnetic field at the center of the magnet (vertical position equal to zero) was measured to be -0.77 T, while the simulated field at the same position was -0.87 T, a reduction of 12%. Figure 2 shows measured and simulated field values at different positions along the beamline. Position zero is the upstream face of the magnet and the peak field (-0.87 T) appears at a position around 30 mm.

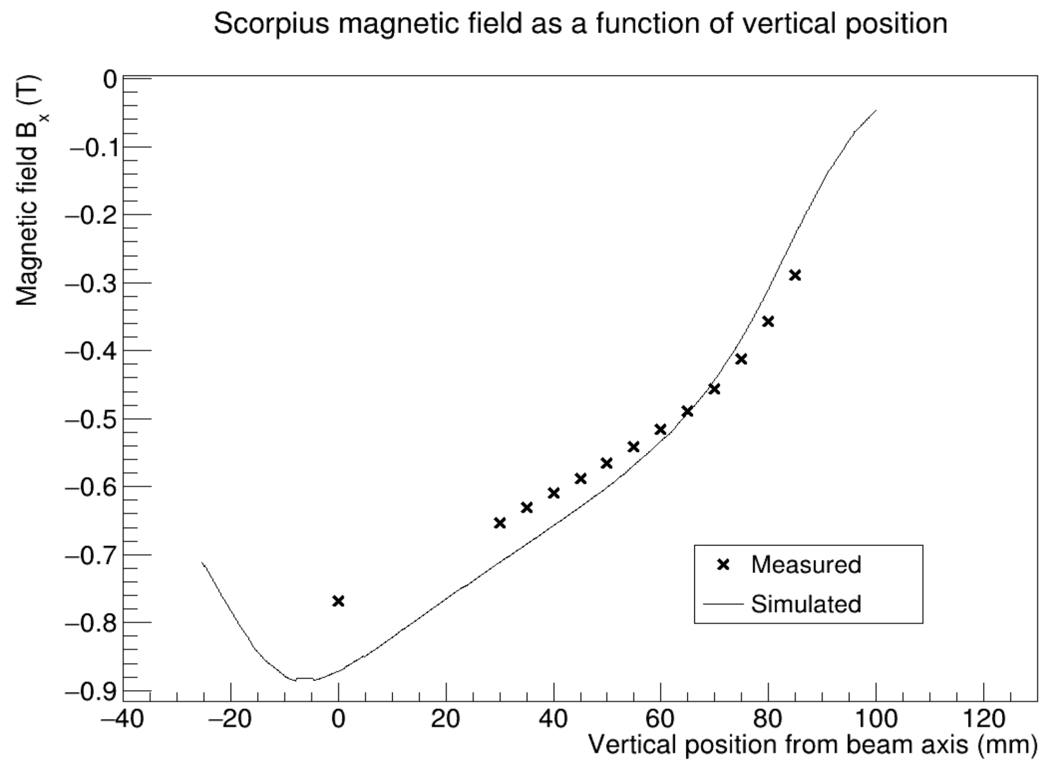

Figure 1 – Scorpius simulated and measured magnetic field (principal component B_x) versus vertical height from beamline. The maximum field value, at vertical position zero, is 12% smaller than the simulation.

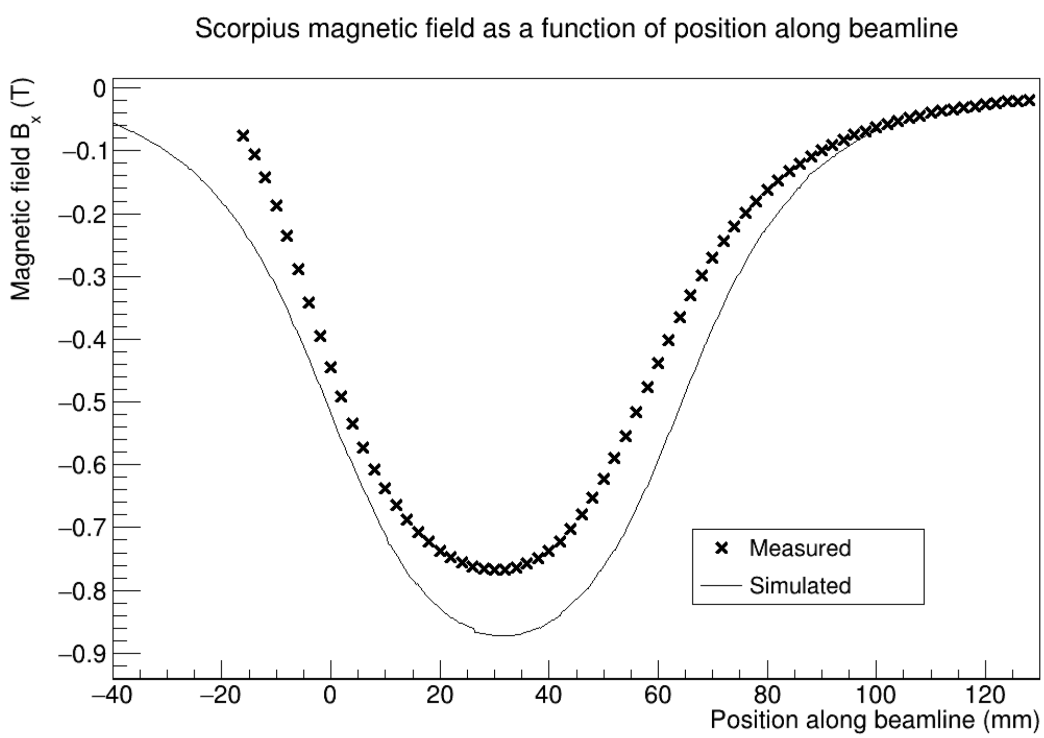

Figure 2 - Scorpius simulated and measured magnetic field (principal component B_x) versus distance along beamline. The maximum field value, at around +30 mm, is 12% smaller than the simulation.

The measured values were used to update the simulation to check the effect of the smaller peak field strength. Figure 3 shows simulated beam deflection results for the designed and the measured fields. As a conservative approximation of the measured case we decreased the field at all points by 20%. The results show that the measured field is adequate to deflect 100% of the beam into the polycrystalline diamond beam dump at bottom.

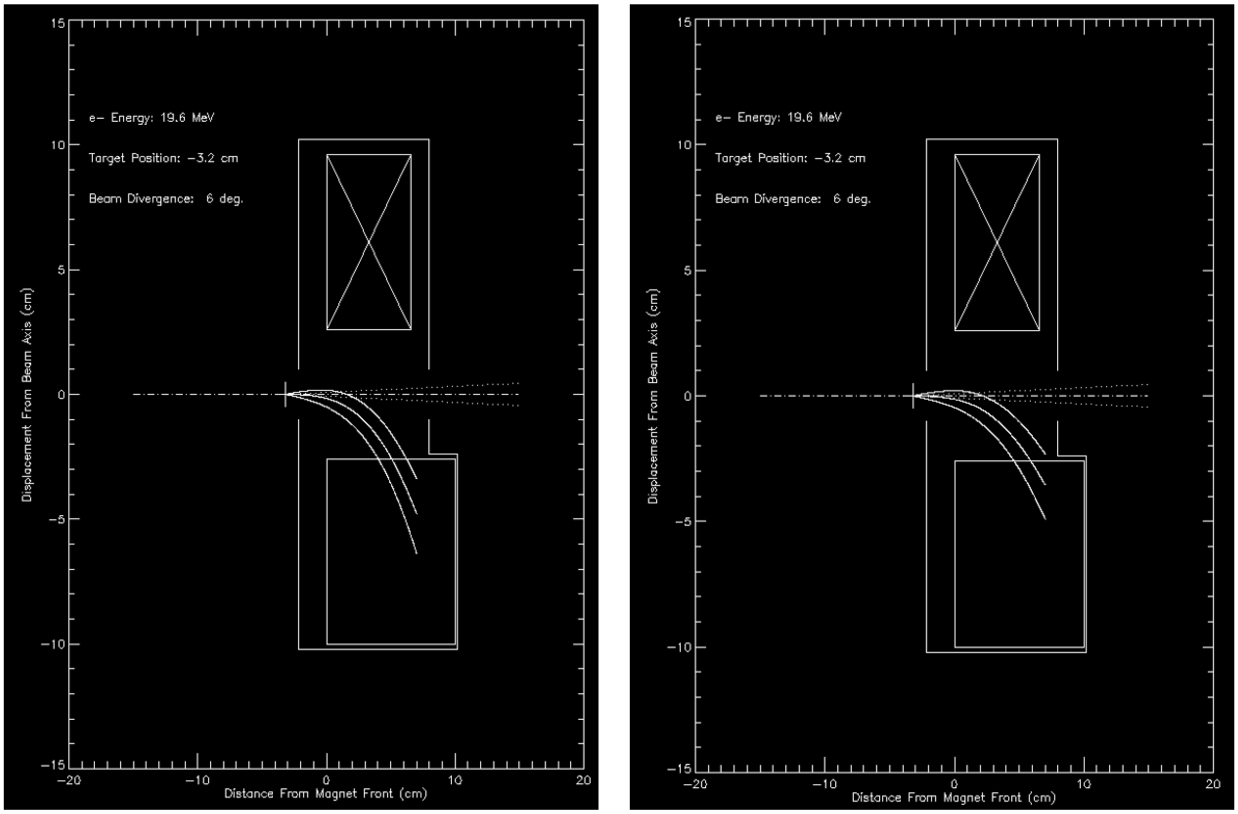

Figure 3 - Simulation result using simulated (left) and an approximation of the measured (right) Scorpius field strengths. Three trajectories are shown, one at zero divergence and two forming an envelope containing 100% of the beam, assuming a typical 2 degree (1 σ RMS) divergence. The block below the beamline is the polycrystalline diamond beam-dump.

We also compared the measured fields along the beamline between the Scorpius and existing DARHT magnets. Figure 4 shows the Scorpius measurement and DARHT [5] measurements overlaid. The DARHT magnet is a complete Halbach cylinder [6], while the Scorpius magnet has a void at the bottom to accommodate a non-magnetic beam-dump. During the design phase it was known that the void would reduce the peak field from the full cylinder design, so the magnet was made 25% longer in the beam direction. In Figure 4 we can see the Scorpius field is predictably weaker in peak amplitude but broader in spatial extent.

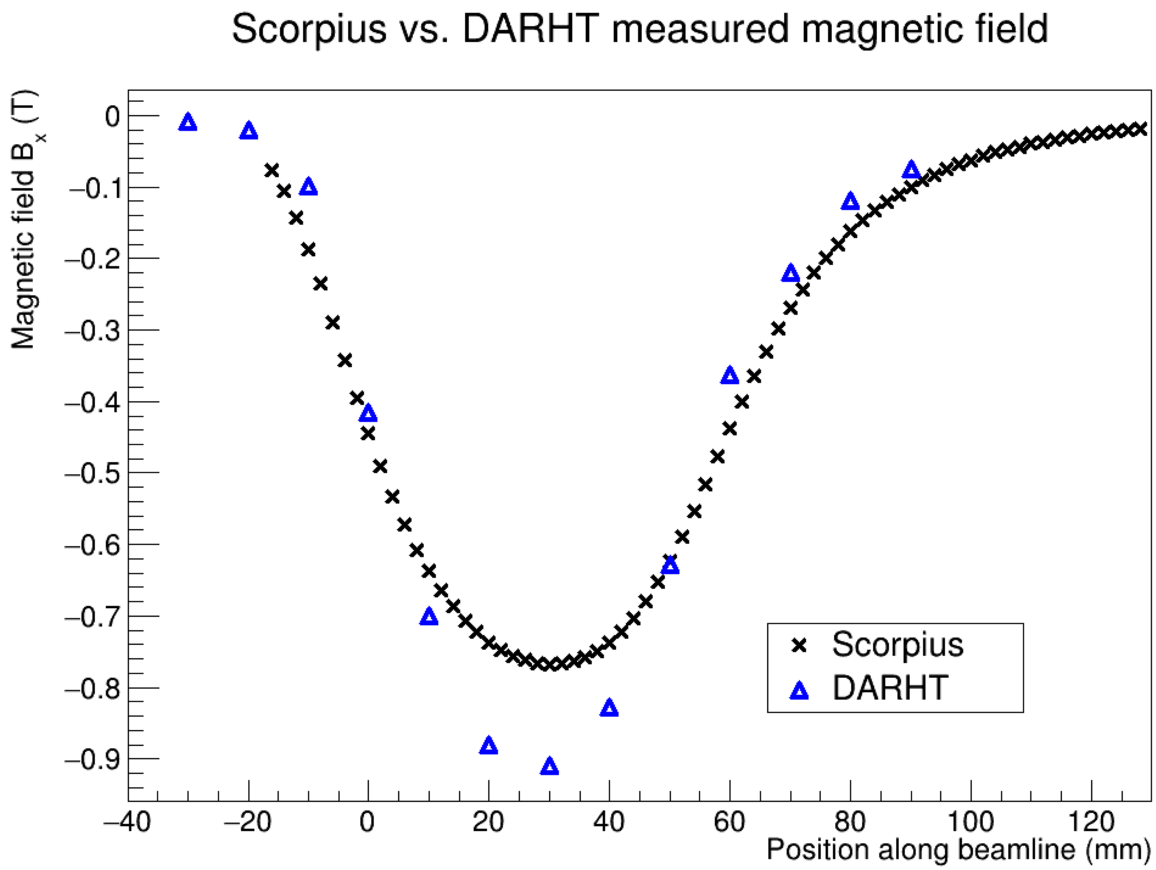

Figure 4 - Magnetic field (T) measured along the beam axis (mm) for the as-built Scorpius and DARHT magnets.

Finally, to evaluate the efficacy of a general magnetic field to deflect an electron beam, the important quantity is $\int B \cdot dl$, which describes the action of the magnetic field (in this case the principal component B_x) on the electron beam along range segments (dl). Table 1 shows this integral value along with the approximate deflection angle in degrees for a 19.6 MeV electron (see [3] for the deflection angle equation derivation). We find that the electron beam deflection angles for both magnets agree to within 5%, and although the Scorpius deflection is weaker, the size of the deflection region is 25% longer. The performance of the delivered magnet is acceptable.

Table 1 - Magnetic action integral and beam deflection angle for Scorpius and DARHT.

	$\int B_x\, dl$	$\theta = \frac{540}{\pi E} \int B_x dl$
Scorpius	5.08 T·cm	44.6°
DARHT	5.31 T·cm	46.6°

References

[1] M. Crawford and J. Barraza, "Scorpius: The development of a new multi-pulse radiographic system," *2017 IEEE 21st International Conference on Pulsed Power (PPC)*, pp. 1-6, 2017.

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[5] Communication with Dave Moir, LANL, 1/13/2022.

[6] K. Halbach, Design of permanent multipole magnets with oriented rare earth cobalt material, *Nuclear Instruments and Methods*, Volume 169, Issue 1, pp 1-10, 1980.